Journal of Engineering Science and Technology
Vol. 9, No. 3 (2014) 334 - 346

INVESTIGATION OF FOULING DEPOSIT FORMATION DURING PASTEURIZATION OF CHILI SAUCE BY USING LAB-SCALE CONCENTRIC TUBE-PASTEURIZER

NUR ATIKA ALI, NURUL IZZAH KHALID, NORASHIKIN AB. AZIZ*, ROSNAH SHAMSUDIN, FARAH SALEENA TAIP

Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
*Corresponding Author: norashikin@upm.edu.my

Abstract

This paper investigates the characteristics of fouling deposits obtained from chilli sauce pasteurization. A lab-scale concentric tube-pasteurizer was used to pasteurize the chilli sauce at 0.712 kg/min and 90±5°C. It was operated for 3 hours. Temperature changes were recorded during pasteurization and the data was used to plot the heat transfer profile and the fouling resistance profile. The thickness of the fouling deposit was also measured and the image was taken for every hour. The fouling deposit was collected at every hour to test its stickiness, hardness and flow behaviour. Proximate analysis was also performed and it shows that the fouling deposit from the chilli sauce is categorized as carbohydrate-based fouling deposits. Activation energy of chilli sauce is 7049.4 $J.mole^{-1}$ which shows a greater effect of temperature on the viscosity. The hardness, stickiness of fouling deposit and the heat resistance increases as the chilli sauce continuously flows inside the heat exchanger.

Keywords: Fouling deposit, Chilli sauce, Pasteurization, Heat exchanger, Heat transfer.

1. Introduction

The accumulation of an undesirable deposit on processing equipment surface is a crucial problem. The fouling deposit has a low thermal conductivity. The increase of thickness of this deposit will create significant resistance to heat transfer [1] in the process equipment. Fouling deposition increases the fluid flow resistance in process equipment, reducing the flow rate of the products and at the same time increasing the pressure drop [2]. Fouling deposit problems in food industries is more harmful compared to other industries as the foulant can be derived from the

Nomenclatures

c_p	Specific heat of fouling deposit, J/kg·°C
dQ/dt	Heat flow, W
dT/dt	Temperature rate, °C/s
E_a	Activation energy of flow, J/mole
m	Mass, kg
R	Gas constant, J/K.mole
T	Absolute temperature, K
U	Overall heat transfer coefficient, J/m^2.s.°C
V	Volume, m^3

Greek Symbols

η	Apparent viscosity, Pa.s
η_a	Consistency index
η_o	Empirical constant

food ingredients during processing and particulate matter might be deposited on the surface of processing equipment. Other than that, heating food ingredients such as sugar at high temperature will cause the sugar to caramelize and become hardened product that will later become a fouling deposit. The formation of the fouling deposit will contaminate the food products and subsequently reducing the product quality [3].

Fouling deposit is also found in chilli sauce process plant. Chilli sauce fouling deposit is categorized as carbohydrate-based fouling deposit. Cleaning of this type of deposit is easy but if caramelization occurs, the cleaning process will be harder [4]. In this paper, the fouling deposit from chilli sauce is investigated by using the lab-scale concentric tube-pasteurizer which has the same experimental set-up of pink guava puree studies by Chan and Ab. Aziz [5] and Khalid et al. [6]. The characteristics of chilli sauce during pre-mixing process and pasteurization process are investigated.

Although there are many previous studies on fouling deposit behaviour, there is no report on chilli sauce fouling deposit. Most of the papers are focusing on fouling deposit from the dairy products [7 -11]. Very few papers are reporting on the local products such as coconuts milk [12]. This fat-based food fouling behaviour and its cleaning was investigated by both in-situ (using lab-scale plate heat exchanger) and ex-situ methods (using shakeable water bath). Fouling study of pink guava juice deposit was reported in Ho et al. [13], which used a basic tubular heat exchanger and in Ong et al. [14], which various ex-situ experimental rigs were setup and the best ex-situ rig was selected.

Lack of references on the chilli sauce and its fouling deposit has given a difficulty to perform cleaning effectively. Thus, the aims of this work were (i) to determine the properties of chilli sauce and its fouling deposit in terms of physical and chemical and (ii) to determine the factors that contribute to the formation of fouling deposit in chilli sauce processing. In the next section, materials and method used for this study is presented in details. Then, it follows by results and discussion which explained the works. Lastly is the conclusion which concludes the study.

2. Materials and Methods

2.1. Model chili sauce

Chili (capsicum annum) sauce is categorized as complex multiphase suspensions. In order to reduce the complexity of the sauce, ingredients such as spices and garlic were not added in the model chili sauce that was used in this study. Table 1 lists the chili sauce ingredients that were used to prepare the model chili sauce which follow the formulation from commercial chili sauce of Pegasus, Thai RoongRueng Chili sauce Co., Ltd. presented by Alam et al. [15].The chili purees and modified corn starch were supplied by AJT Food Sdn. Bhd., Selangor, Malaysia. Other ingredients were purchased from a local supermarket.

Table 1. Modified Formulation of Chilli Sauce.

Ingredients	Percentage (%)
Chilli puree	28
Liquid Sugar	17
Salt	16
Vinegar	10
Modified corn starch	2

In this study, the experiment was set-up for 3 hour pasteurization process, which 130 kg of chili sauce was needed. In pre-mixing process, the mixer tank was used to mix the chili puree and the vinegar for 15 minutes. The pre-blended mixture: modified corn starch, liquid sugar and salt, was added when the pre-mixing was completed. Then, all of the ingredients were mixed for 30 minutes. The pH and the TSS of the prepared chili sauce model were measured before the pasteurization process.

2.2. Experimental setup

The lab-scale concentric tube-pasteurizer, as shown in Fig. 1, was designed specifically for viscous food liquid. It has 4 concentric tubes with temperature sensor at the beginning and at the end of each tube which allow temperature to be recorded. The lab-scale concentric tube-pasteurizer was operated for 3 hours to ensure sufficient data can be collected. The temperature sensors are also located at the output and input of the heating tank. Temperature data was recorded for every 3 minutes. The data was used to plot the heat transfer profile and the fouling resistance profile. The inner diameter of each tube is 2.25 cm and the tube length is 100 cm.

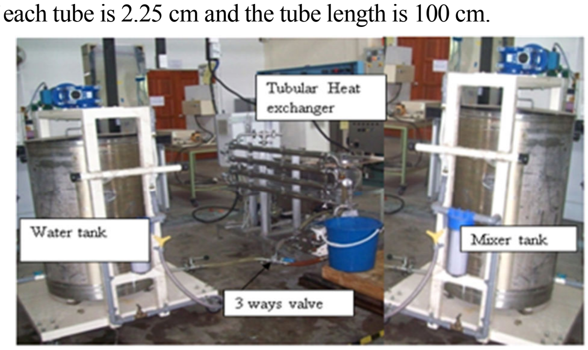

Fig. 1. Lab-Scale Concentric Tube-Pasteurizer.

The chilli sauce was pasteurized at 90±5°C, 0.712 kg/min with holding time of 120 s. Each tube of the lab-scale concentric tube-pasteurizer was weighed before every pasteurization operation, Fig. 2. The tubes were dismantled at every hour during pasteurization and the weight was measured again. The weight was used to measure the density of the fouling deposit. This data was used to calculate the fouling thickness. The images of each tube were captured for observation. All the calculation for heat transfer profile and fouling resistance profile are based on Chan and Ab. Aziz [5] and Khalid et al. [6].

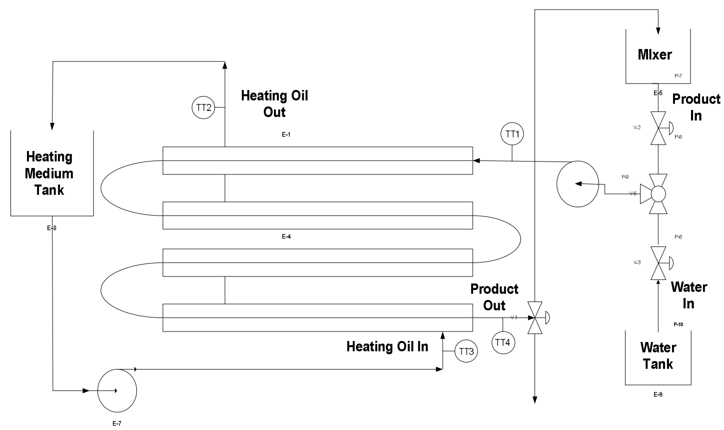

Fig. 2. PI&D of the Lab-Scale Concentric Tube-Pasteurizer.

2.3. Analytical Method

The measurement of protein was carried out by Kjeldahl method. The Soxhlet method was used to determine fat content and the oven method was used to determine moisture content. Muffle furnace was used to determine ash content by drying the chili sauce up to 550°C. All this proximate analysis was performed according to AOAC standard method [16]. The pH of chili sauce was measured by a pH meter. Total soluble solid of chili sauce was measured using Digital ABBE Refractometer (AR-2008, Kruss, Germany). Measurements of pH and total soluble solid were carried out 3 times and the average for each was taken.

The density of the chili sauce fouling deposit was determined using a beaker. 200 ml of the chili sauce was weighed. The density was obtained from Eq. (1) [6]. The thermal conductivity of the chili sauce during pre-mixing was measured by thermal properties analyzer (KD2, Decagon, Washington) at 28°C. Specific heat capacity of the chili sauce was determined using a differential scanning calorimeter (DSC) (DSC-7, Perkin-Elmer, USA). The temperature range was set from 20ºC to 90ºC with temperature rate of 10°C/min and the results were used to determine the specific heat capacity by using Eq. (2) [17]. Measurement was conducted two times and the average was taken.

$$\text{Density} = \frac{\text{mass}, m}{\text{volume}, V} \tag{1}$$

$$\text{Specific Heat, } c_p = \frac{dQ/dt}{dT/dt} \tag{2}$$

where *dQ/dt* is heat flow, *m* is chilli sauce weight and *dT/dt* is temperature rate.

Measurement of stickiness and hardness of chili sauce fouling deposit were performed according to Ho et al. [13]. These properties were obtained from texture analyzer (TA-XT Plus, Stable Micro Systems, UK). Each test was repeated for five times and the average was taken. The parameter and specification of texture analyzer for executing hardness and stickiness analyses are shown in Table 2, which adapted from Kukulka et al. [2].

Table 2. Parameters and Specification of Texture Analyser for Hardness and Stickiness Analysis for Chilli Sauce Fouling Deposit.

Parameter	Value	Description
Probe	P20	The size of probe used: cylindrical; 20mm
Test- Mode	Compression	Initial probe direction and force polarity
Pre- Test speed (mm/s)	2	Probe speed while searching for trigger point
Test Speed (mm/s)	1	Speed of approach to target distance after triggering
Post test speed (mm/s)	2	Speed at which the probes returns to start point.
Target mode	Strain	Target parameter.
Strain (%)	50	Specify target strain base on trigger height
Trigger type	Auto	To define the method of the initiation of data
Trigger force (g)	4	Amount of force for TA to initiate data capture
Stop plot at	Start position	-
Break mode	Off	-
Tare Mode	Auto	-
Advanced Options	On	-

Dynamic viscoelasticity and viscous flow tests were performed using a stress rheometer (Dynamic Controlled Stress 600 Rheometer, Mermo Electron Corporation, Germany). The tests were carried out using serrated plate-plate geometry (35mm, 1-mm gap) [18]. O'Leary et al. [19] stated that wide range of shear rates was tested in order to measure apparent viscosity during slow deformation involved in tipping fluid in a beaker (estimated to be $0.1s^{-1}$) and during the faster deformation in a normal swallow (estimated to be $100s^{-1}$). The flow behavior of the chili sauce was monitored at different temperatures (20, 30, 40, 50, 60, 70, 80, and 90°C) and subjected to a programmed logarithmic shear rate ramp increasing from 10 to 100 s^{-1}.Arrhenius equation analysis was applied in this work to explain the temperature effects on the flow behavior of chili sauce. Equation (3) is the same equation that applied for fresh and commercial pink guava puree [20]. High activation energy values indicate a high dependency of the viscosity on the temperature.

Arrhenius equation,

$$\eta_a = \eta_0 \exp(\frac{E_a}{RT}) \tag{3}$$

where η_a is the consistency index, η_o is empirical constant, E_a is the activation energy of flow, R is the gas constant and T is the absolute temperature in kelvin.

3. Results and Discussion

3.1. Chemical properties

The component of the chilli sauce fluid and its fouling deposit was identified from the composition analysis. Percentage of moisture is decreasing after pasteurization by referring to Table 3. The decreasing moisture is due to evaporation that occurred during pasteurization, thus led to water loss in the chilli sauce. According to Grasshoff [4], fouling deposit is categorized based on its main composition. For this study, chilli sauce fouling deposit is classified as carbohydrate-based fouling as carbohydrate composition gives the highest percentage. According to Grasshoff [4], it can be concluded that the carbohydrate-based deposit is easy to remove, but the cleaning process will be harder if caramelization occurred.

Table 3. Chemical Properties of Chilli Sauce.

Component (%)	Chilli sauce	Chilli sauce fouling deposit
Oil	0.2788	2.2854
Moisture	59.7051	20.4444
Ash	14.4626	24.1821
Protein	1.3723	2.71
Fibre	1.6429	3.8576
Carbohydrate	22.5382	46.5205

3.2. Physical properties

The pH of chilli sauce is 3.673 and it lies in range between 3.43-3.93 which indicates an acidic characteristic. Vinegar included in the recipe, which has known as acidic ingredient certainly gave the acidic characteristic. Due to presence of sugar and salt, the total soluble solid value is 40.8 °Brix. Specific heat and thermal conductivity of the sauce are 2129 J/kg°C and 0.39 W/m°C respectively. From Table 4, it can be seen that the density increased from 1140.4 kg/m^3 to 1350 kg/m^3 as the time increased. This phenomenon occurred because moisture of chilli sauce was vaporised during heating process which caused the mass of chilli sauce to be higher than its volume.

In this study, the hardness and stickiness of chilli sauce fouling deposit performance are illustrated in Figs. 3 and 4. These figures show that hardness and stickiness are directly proportional with time. The existence of strong covalent bond may become more extensive within the deposit as heating time is increased. In this study, the hardness of chilli sauce was gradually increased over the time as the heating enhanced the evaporation of water from the chilli sauce. Basically, raw material used in the recipe affect the hardness of chilli sauce. Chilli sauce mixture contains high percentage of sugar and some non-soluble fibre which caused the hardening of chilli sauce when contact with high temperature. The chilli skins and seeds could be the source for the non-soluble fibre. Thus the hardness of fouling deposit increased as the chilli sauce continuously flowed inside the heat exchanger for 3 hours.

Table 4. Density of Chilli Sauce.

Time	Density (kg/m^3)
0	1140.4
1	1150
2	1200
3	1350

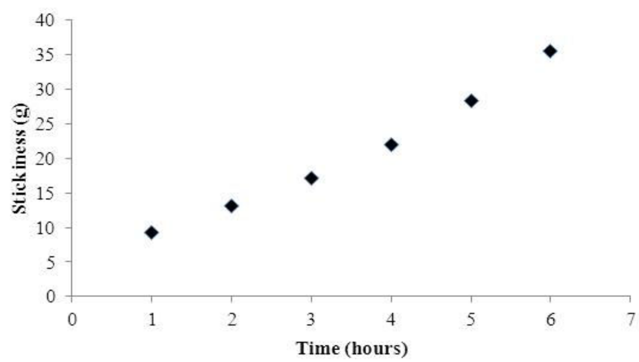

Fig. 3. Stickiness (g) as a Function of Time (min.) for Chilli Sauce Fouling Deposit.

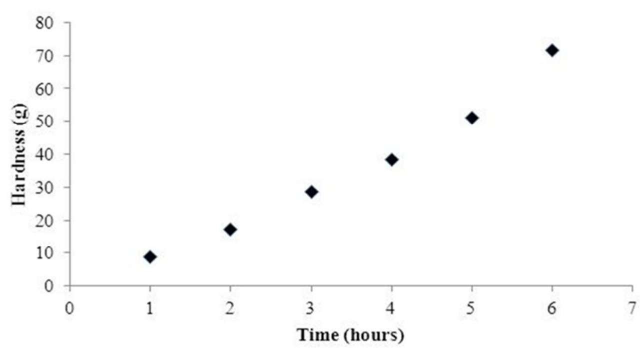

Fig. 4. Hardness (g) as a Function of Time (min.) for Chilli Sauce Fouling Deposit.

3.3. Flow behavior

In food industry, hydrocolloid which is a high molecular weight hydrophilic biopolymer was used as functional ingredients to control the food microstructure, texture, flavour and shelf life [21]. Generally, high content of hydrocolloid contributes to high pseudo plasticity behaviour [22]. In this work, modified corn starch acted as hydrocolloid which provides high viscosity and gives pseudo plasticity behaviour to the chilli sauce. However, the existence of acetic acid tends to reduce its viscosity. This is because acetic acid encourages the fragmentation of starch chain into much shorter length so the gelation and disintegration of the granule occurred at low temperature. The relationship between apparent viscosity and shear rate is shown in Fig. 5. The curve had shown pseudo plastic behaviour where the apparent viscosity is inversely proportional with shear rate.

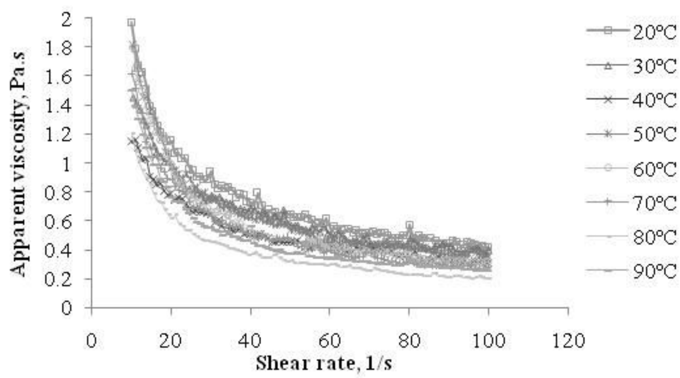

Fig. 5. Apparent viscosity as a Function of Shear Rate (1/s) for Chilli Sauce at Different Temperature.

The trend of flow behaviour in Fig. 6 is similar to that of Koocheki et al. [22] which studied flow behaviour of ketchup. The parameter was obtained by fitting the data of apparent viscosity at shear rate = 30^{-1} as a function of temperature. The application of Arrhenius type model was assessed in observing the dependency of viscosity of ketchup on temperature [22]. The high value of R^2 which is 0.746 showed the relation of chilli sauce viscosity to the temperature, which obeys the Arrhenius type behaviour. Generally, the higher activation energy results in greater effect of temperature on the viscosity [23]. Activation energy, E_a of chilli sauce is 7049.4 J mole^{-1} which lies in the range of the activation energy of ketchup with addition of hydrocolloid studied by Sanzet al. [18]. According to Marcotteet al. [24], addition of starch, pectin and gelatine would give intermediate values of activation energy after describing temperature effect on apparent viscosity of some food hydrocolloid which evaluated by applying Arrhenius behaviour model. Even though the viscosity of the chilli sauce was decreased with the increase of time, the chilli sauce gelling structure would be maintained by modified corn starch which gives stickiness effect on chilli sauce. Thus, it would lead to the formation of fouling deposit inside the tube.

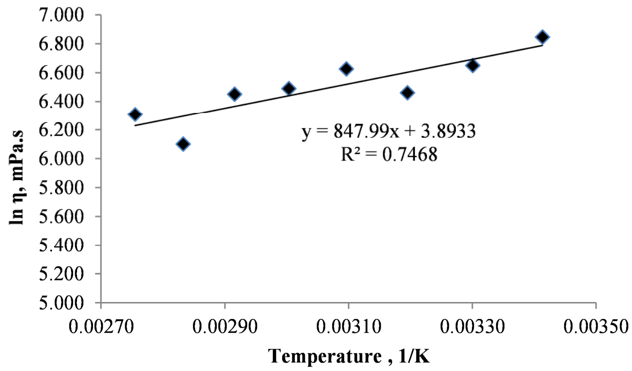

Fig. 6. Apparent Viscosity at Shear Rate = 30 s^{-1} as a Function of Temperature for Chilli Sauce.

3.4. Heat transfer analysis

Correlation of overall heat transfer coefficient with fouling resistance at every tube can be seen in Figs. 7 and 8. The overall heat transfer coefficient gradually decreased from tube 1 to tube 4. Fouling deposit was accumulated inside the tube during the experiments. Thus, it provided a barrier for heat transfer. However, the opposite had happened for fouling resistance result which shown in Fig. 8. Fouling resistance is inversely proportional to the overall heat transfer coefficient. The fouling resistance is highest in tube 4 compared with other tubes because the deposition rate in tube 4 is the highest among the tubes.

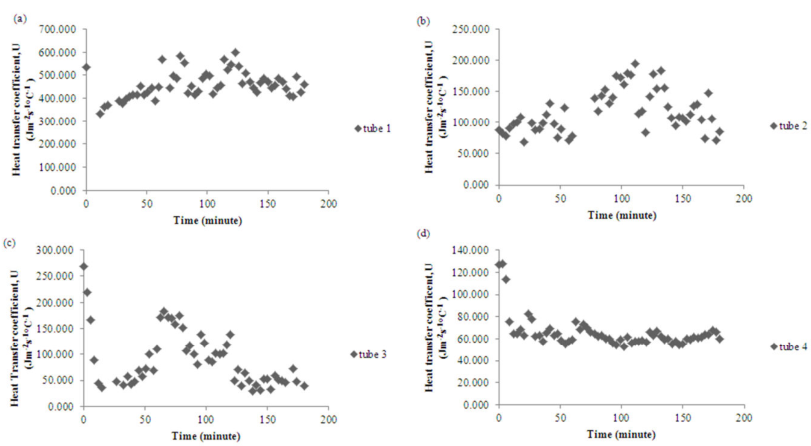

Fig. 7. Heat Transfer Profile of a) Tube 1, b) Tube 2, c) Tube 3, d) Tube 4.

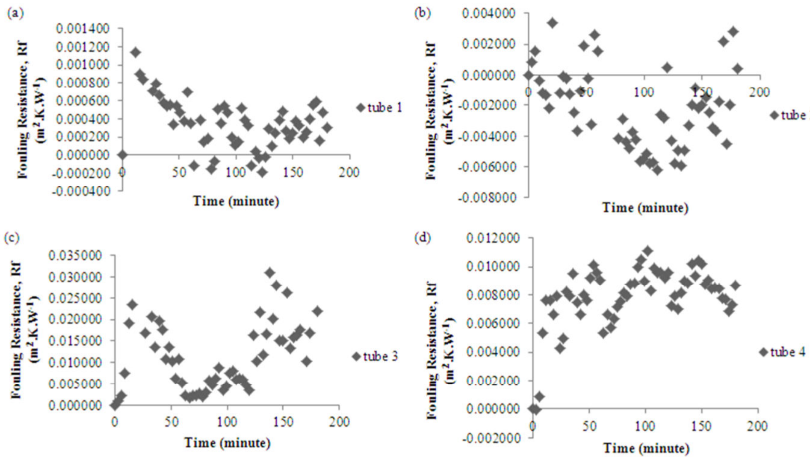

Fig. 8. Fouling Resistance Profile of a) Tube 1, b) Tube 2, c) Tube 3, d) Tube 4.

Fouling deposit thickness is a phenomenon which has direct effect on the overall heat transfer coefficient and fouling resistance data. It affects the fouling deposit resistance where the increasing thickness of the fouling deposit on tube inner surface causes the reduction in heat transfer. Figure 9 shows that tube 4 has the highest thickness of fouling deposit layer. It is because the wall temperature in tube 4 is the highest as the heating oil flows from tube 4 to tube 1, thus tube 4 has the highest temperature gradient. Fryer [25] stated that by having high wall temperature, the fouling becomes more severe. Figure 10 shows the accumulation of fouling deposit in the tubes after 3 hours.

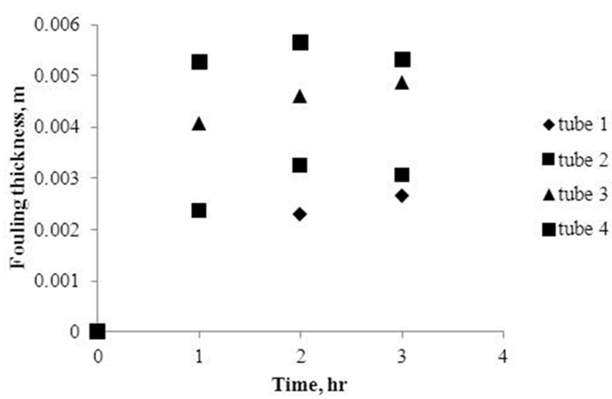

Fig. 9. Fouling Deposit Thickness Profile at Every Tube after 3 Hours.

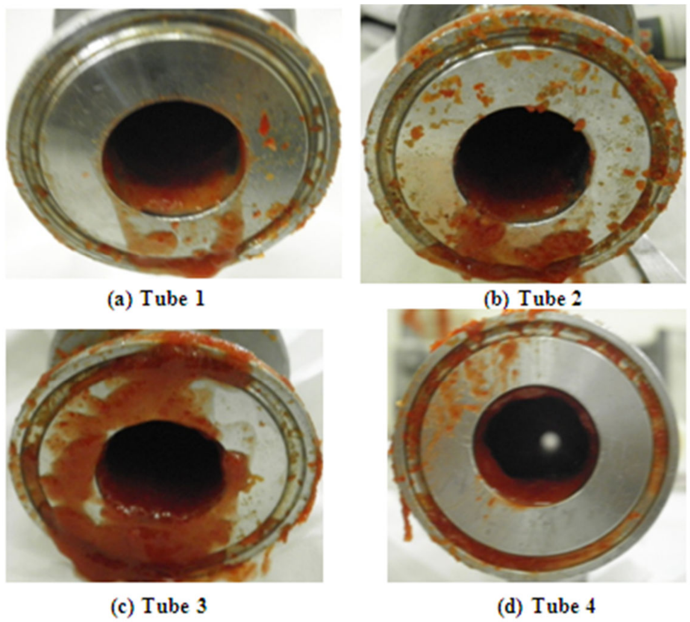

Fig. 10. Picture of Chilli Sauce Fouling Deposit after 3 Hours Operating.

4. Conclusions

An investigation has been made on the fouling deposit formed from pasteurization of chilli sauce. The physical characteristics and heat transfer analysis were interpreted by using analytical methods. Therefore, some conclusions have been made:

- Formation of chilli sauce fouling deposit is mainly because of temperature and its composition. Besides temperature and composition, the duration of equipment operation also increases the fouling formation. The fouling deposit from chilli sauce is categorized as carbohydrate-based fouling deposit which mostly contributed by the chilli puree and modified corn starch. The molecular behaviour of the chilli sauce ingredients also affected the hardness and stickiness of the chilli sauce fouling deposit.
- Thickness of fouling deposit inside the tubes did affect both overall heat transfer coefficient and fouling resistance. The overall heat transfer coefficient is inversely proportional to fouling resistance. The increased of the fouling resistance is caused by the increased thickness of fouling deposit in the tubes by time.
- As the heating process is going on, chilli sauce fouling deposit is expected to continuously build-up and will be hardened by time. Formation of fouling deposit will be minimal if the duration of equipment operation is reduced. However this is not applicable as it will reduce the productivity of the food manufacturer. Thus, a correlation between fouling and cleaning data of chilli sauce fouling deposit need to be obtained to find the optimum schedule for pasteurization and cleaning.

Acknowledgement

This author would like to express their gratitude to Department of Process and Food Engineering and to Universiti Putra Malaysia and to all people who contributed to the present work.

References

1. Bott, T.R. (1995). Fouling of heat exchangers. *New York: Elsevier Science & Technology Books.*
2. Kukulka, D.J.; Czechowski, H.; and Kukulka, P.D. (2010). Factors associated with fouling in the process industry. *Heat Transfer Engineering*, 31(9), 782-787.
3. Hongda Chen (2003). Surface fouling during heating. In: *Encyclopedia of Argicultural Food and Biological Engineering* (Edited by Dennis R. Heldman), pp. 975-978. New York: Marcel Dekker.
4. Grasshoff, A. (1997). Cleaning of heat treatment equipment, IDF monograph, *Fouling and cleaning in heat exchangers*.
5. Chan, K.W.; and Ab. Aziz., N. (2011). Pasteurization of pink guava puree: Fouling deposit study. *Proceeding of Regional Symposium on Engineering and Technology* 2011. Kuching, Sarawak, Malaysia, 1-6.
6. Khalid, N.I.; Chan, K.W.; Ab Aziz, N.; Taip, F.S.; andAnuar, M.S. (2013). Concentric tube-fouling rig for investigation of fouling deposit formation from pasteuriser of viscous food liquid. *Journal of Engineering Science and Technology* (*JESTEC*), 8(1), 16-26.
7. Grijspeerdt, K.; Mortier, L.; De Block, J.; and Van Renterghem, R. (2004). Applications of modelling to optimise ultra high temperature milk heat exchangers with respect to fouling. *Food Control*, 15(2), 117-130.
8. Nema, P.K.; and Datta, A.K. (2005). A computer based solution to check the drop in milk outlet temperature due to fouling in a tubular heat exchanger. *Journal of Food Engineering*, 71(2), 133-142.
9. Sahoo, P.K.; Ansari, I.A.; and Datta, A.K. (2005). Milk fouling simulation in helical triple tube heat exchanger. *Journal of Food Engineering*, 69(2), 235-244.
10. Simmons, M.J.H.; Jayaraman, P.; and Fryer, P.J. (2007). The effect of temperature and shear rate upon the aggregation of whey protein and its implications for milk fouling. *Journal of Food Engineering*, 79(2), 517-528.
11. Rosmaninho, R.; Santos, O.; Nylander, T.; Paulsson, M.; Beuf, M.; Benezech, T.; Yiantsios, S.; Andritsos, N.; Karabelas, A.; Rizzo, G.; Müller-Steinhagen, H.; and Melo, L.F. (2007). Modified stainless steel surfaces targeted to reduce fouling - Evaluation of fouling by milk components. *Journal of Food Engineering*, 80(4), 1176-1187.
12. Law, H.Y.; Ong, C.I.; Ab. Aziz, N.; Taip, F.S.; and Muda, N. (2009). Preliminary work on coconut milk fouling deposits study. *International Journal of Engineering & Technology*, 9(10), 8-13.
13. Ho, A.L.; Tan, V.C.; Ab. Aziz, N.; Taip, F.S.; and Ibrahim, M.N. (2010). Pink guava juice pasteurisation: Fouling deposit and cleaning studies. *Journal - The Institution of Engineers*, *Malaysia*, 71(4), 50-62.

14. Ong, C.A.; Abdul Aziz, N.; Taip, F.S.; and Ibrahim, M.N. (2012). Ex-situ experimental set-up for pink guava juice fouling deposit study. *Pertanika Journal of Science & Technology*, 20(1), 109-119.
15. Alam, M.K.; Ahmed, M.; Akter, Mst. S.; Islam, N.; and Eun, J.-B. (2009). Effect of carboxymethylcellulose and starch as thickening agents on the quality of tomato ketchup. *Pakistan Journal of Nutrition*, 8(8), 1144-1149.
16. Association of Analytical Chemist (AOAC) (1995). *Official methods of analysis of the association of official analytical chemists*. 16th Ed. Arlington, Va; AOAC
17. Bantle, M.; Eikevik, T.M.; Brenvall, J.E. (2010). A novel method for simultaneous and continuous determination of thermal properties during phase transition applied to *Calanus finmarchicus*. *Journal of Food Science*, 75(6), E315-E322.
18. Sanz, T.; Salvador, A.; and Fiszman, S.M. (2008). Evaluation of four type resistant starch in muffin baking performance and relationship with batter rheology. *European Food Research & Technology*, 227(3), 813-819.
19. O'Leary, M.; Hanson, B.; and Smith, C.H. (2011). Variation of the apparent viscosity of thickened drinks. *International Journal of Language & Communication Disorder*, 46(1), 17-29.
20. Chan, K.W.; Ab Aziz, N.; Muda, N.; Shamsuddin, R.; and Taip, F.S. (2012). An evaluation of commercial pink guava puree properties as a potential model fouling fluid. *Journal of Food*, *Agriculture & Environment*, 10(3 & 4), 60-66.
21. Dickinson, E. (2003). Hydrocolloids at Interfaces and the Influence on the Properties of Dispersed System. *Food Hydrocolloids*, 17(1), 25-39.
22. Koocheki, A.; Ghandi, A.; Razavi, S.M.A.; Mortazavi, S.A.; and Vasiljevic, T. (2009). The rheological of ketchup as a function of different hydrocolloid and temperature. *International Journal of Food Science & Technology*, 44(3), 596-602.
23. Mohd Nurul, I.; Mohd Azemi, B.M.N.; and Manan, D.M.A. (1999). Rheological behaviour of sago (Metroxylonsagu) starch paste. *Food Chemistry*, 64(1), 501-505.
24. Marcotte, M.; Hashahili, A.R.T; and Ramaswamy, H.S. (2001). Rheological properties of selected hydrocolloid as a function of concentration and temperature. *Food Research International Journal*, 34(8), 695-703.
25. Fryer, P.J. (1989). The use of fouling model in the design of food process plant. *International Journal of Dairy Technology*, 42(1), 23-39.